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(54) EXTRUSION METHOD AND APPARATUS

(71) I, OLE-BENDT RASMUSSEN, a Danish citizen, of 7 Topstykket, DK-3460 Birkerød, Denmark, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

Various ways of extruding material as a cylindrical product, that may be continuous or filamentary or fibrous, are known.

In U.S. Patent No. 3,281,897 two counterrotating exit parts form two circular helically twisted arrays of continuous filaments, which join at their cross-points due to the shape of the orifices, by which a netstructure is formed. This and closely related methods are widely used but have drawbacks or limitations, e.g. in that the mesh has to be relatively wide and the filaments relatively coarse.

Another way of effecting the extrusion is disclosed in U.S. Patents Nos. 3,505,162, 3,565,744, and 3,677,873. The basic ideas of these patents is to join streams of different materials to fluid sheet form in an internal chamber of the die and twist the streams helically while strongly attenuating them by means of a rotating internal part. ("Attenuation" involves drawing of a molten stream). The die may comprise a fixed row of internal orifices, which extrude the components in interspersed relationship, a first annular collecting chamber, a rotating annular row of partitions, and a second annular collecting chamber directly leading into an annular exit slot. The interspersed arrangement of different materials is utilised to form a layer which has a substructure that is fibre-like and of "lamellar" shape. The layer can be laminated with a layer of different grain to form a high-strength film. Alternatively, the layer may be disrupted to obtain a non-woven fabric. Since the attenuation takes place in several steps, very thin lamellae can be achieved, but because the partitions result in the lamellae being cut into discontinuous lengths and undergoing irregular attenuation the substructure is uneven and this lessens the strength properties.

Another method disclosed in the same three patents consists in rotating the row of internal orifices, which extrude the components in interspersed relationship, and immediately joining the streams in the collecting chamber directly leading to the exit slot. This produces continuous and very even lamellae, but a much higher speed of rotation is required to achieve the same low thickness of the lamellae. Unfortunately the melt orientation created by such high rotation leads to high elastic tensions in the extruded tube even after the exit from the die. This results in the tube having a very pronounced tendency to shrink to a smaller diameter and so the control of the extrusion is difficult.

Another way of effecting the extrusion is known from U.S. Patent No. 3,632,711. In this there is relative rotation between two concentrical dieparts forming two cylindrical walls in an annular passageway through which the material is extruded on its way to a cylindrical exit slot. Two or more components are passed side-by-side through the passageway and streams of the components are smeared out to form fine layers. These layers are subsequently combed by means of inwardly pointing teeth assembled on the two rotating walls, whereby the sheet acquires a fibrous substructure with criss-crossing grain. The substructure is either utilized for production of high-strength film, or it is disrupted to a non-woven fabric.

However, this method and apparatus have several drawbacks. One is that the fine teeth are difficult to maintain. Another is that the attenuation takes place in a direction which is different from the combing, and so notches or other irregularities are formed in the fibres.

The present invention is intended to permit the manufacture of products of the same general type but while avoiding or reducing the above mentioned drawbacks.

According to the invention an extruded product is made by a method comprising extruding fluid material through an annular die to an extrusion exit while rotating the die around the axis of the annulus and collecting the extruded material on a collector while moving the collector substantially along the axis of the annulus, wherein the collector at least in the area where it collects the extruded material is substantially cylindrical and is substantially coaxial with the annulus and comprises an internal support for the extruded material or is supported by an internal support, and in which method the speed of rotation of the die and of movement of the collector are such that the extruded material is stretched and is given a grain direction on the collector that is at a substantial angle to the axis of the annulus, and the extruded material after solidification is released from the support.

Apparatus according to the invention suitable for carrying out this method comprises a rotatable annular die having an extrusion passage leading to an extrusion exit, means for feeding fluid material to the extrusion passage and extruding it from the exit, and means for moving a collector on which material extruded from the exit may be collected substantially along the axis of the annulus, wherein the collector at least in the area where it collects the extruded material is substantially cylindrical and is substantially coaxial with the annulus and comprises an internal support for the extruded material or is supported by an internal support, and means for rotating the die and for moving the collector such that the extruded material is stretched and is given a grain direction on the collector that is at a substantial angle to the axis of the annulus, and means for releasing the extruded material from the support after solidification of the material.

The extruded product may take a variety of forms. For instance it may be in the form of a sheet, board, tube or pipe or may be filamentary or fibrous. All such forms may be referred to as sheet like structures. It is initially formed as a sheet like cylindrical structure on the collector but after solidification on the collector it may be released from the collector. As explained below this may involve release from the collector or part of the collector may be a film which is laminated to the extruded material and remains part of the extruded product, in which event the release is solely from the support beneath the collector. The fluid material must be fluid at the time it is being extruded and must be solid before the extruded product is released from the support. Solidification may occur on the collector or immediately before collection.

An essential feature of the invention is that the die rotates at a speed which is such that the extruded material is stretched and given a grain direction that is at a substantial angle to the axis. The speed of rotation for any particular grain direction will be dependent partly on the speed of movement of the collector and so the two should be selected appropriately. As shown in the drawings the grain direction is often at a very large angle to the axis of the annulus. Since the extruded material is directly collected on the collector many of the above-mentioned drawbacks are eliminated. Thus the transverse elastic tension produced by the rotation now becomes an advantage, since it helps to transfer the material precisely. Further, the location of collector close to the die exit facilitates a stronger attenuation or deeper draw-down which in turn facilitates the production of very fine filaments and/or high melt-orientation. A further significant advantage of the invention is that it enables the production of a sheet with a grain that is strongly transverse to the length direction and that is made by high fluid drawing of a fluid extrudable material which otherwise might easily break during drawing, e.g. a molten polymer of irregular composition, a molten or dissolved polymer or pre-polymer with composition containing a high content of solid staple fibres, or an extrudable mass of fibres in swollen state, such as swollen collagen fibres.

Depending on the intended use and the material extruded, the stretching by rotation can be carried out either in a free space between the exit and the collector means or in a generally annular "shear-chamber" defined by the inner face of the die and the collector conveying means, the rates of feed and conveying being adjusted to each other so as to maintain the chamber filled with material in a substantially pressure-free state. The stretching in a "shear-chamber" between die and collecting means provides for the most efficient conveying of the material and therefore is generally preferable in the case of materials which are difficult to stretch, while the stretching in a free space has an advantage e.g. for the construction of the apparatus since the friction between the fluid material and the apparatus parts (exit of the die and collecting means) is avoided.

The invention is very suitable for producing continuous sheet-like structures (as opposed to open fabric structures) exhibiting a substructure composed of continuous or almost continuous filaments. This can be achieved by discharging the material as free filaments from the exit of the rotating die while adjusting the rate of feed and conveying of material, and speed

of rotation, to one another so as to lay-up the filaments sufficiently densely on the conveying means as to form a continuous sheet. Another embodiment which also primarily aims at the manufacture of a continuous sheet-like structure with a transverse, highly melt-stretched fibrous substructure, is characterised by extruding different materials in side by side relationship and merging the streams with one another. The filamentituous substructure hereby becomes particularly distinct. Said merging can be carried out before the exit from the rotating die, and/or in a "shear-chamber" between the exit and the collector and/or during collection of filaments on the collector means. A comparison between the three possibilities is given in connection with the description of Figures 5 to 8.

The side by side extrusion and merging of different materials can also with advantage be used for manufacture of structures other than continuous sheet-like structures, e.g. for non-woven fabrics. No matter whether continuous sheet structures or other structures are taken up on the conveying means, the merging of streams of different materials can with advantage be carried out in a regular pattern which at the same time as it involves a side by side arrangement, also involves an embedment, at least in part, of a second material in a first material. This generally results in higher strength in the manufactured product.

An example hereof is the procedure explained in connection with Figures 5 to 7 in which one of the "lamella" components also forms continuous surface layers so that the lamellae of a different component are fully embedded. A more pronounced incorporation, very useful e.g. in connection with the manufacture of high-strength film, is achieved when the exit through which the first material is extruded is in the form of a multitude of relatively long slots extending in the direction of the axis of the rotation and arranged in a circular array around the annulus and the exit through which the second material is extruded is in the form of groups of smaller orifices between the longer slots, the groups being preferably linear groups extending generally axially, and the materials are merged substantially immediately after extrusion. The fibrous substructure of a continuous sheet structure manufactured according to the invention can be achieved without separate extrusion of filaments or regular interspersing of different streams, and can be a random substructure, having a distinct direction of grain. This is possible when the extruded material is a non-homogeneous blend of fluid polymers and a continuous sheet structure is discharged from the exit.

Continuous sheet structures produced in this manner are very useful e.g. as plies in laminated, oriented high-strength film, or in connection with a subsequent swelling or dissolving of one component and fibrillation to a coherent split-fibre web, c.f. U.S. Patent No. 3,499,822. In both cases, the use of the present invention enables a particularly strong melt-drawing which is highly advantageous for the strength properties of the final product.

Another embodiment of the invention yielding a random substructure involves the use, as extruded material, of a blend of fluid polymer material and solid staple fibres, and a continuous sheet structure is discharged from the exit. The incorporation of such fibres can be for filling and/or reinforcement purposes. The method results in a very efficient transverse alignment of the solid fibres and surprisingly high contents of fibres are allowable.

A further use of the invention in connection with the obtaining of a highly melt-drawn, random fibrous substructure consists in discharging a molten polymer capable of segregating into different distinct fibrous polymer fractions when stretched in molten state and solidified, preferably a polymer with high contents of very high molecular weight, and a continuous sheet structure is discharged from the exit. This embodiment is particularly suitable for manufacture of layers in laminated high-strength film. Alternatively, the extruded material can be a polymer with contents of a solvent or swelling agent, whereby a continuous sheet structure is discharged from the exit, and the solvent or swelling agent is caused to segregate in the polymer during the solidification. This embodiment is particularly suitable for the manufacture of film for fibrillation. In another method the extruded material is a polymer which contains dispersed droplets or bubbles of liquid matter, and a continuous sheet structure is discharged from the exit.

Preferably the extrusion is conducted using a fast rotating die, while avoiding the abrasion of seals and other problems normally connected with extrusion of very viscous material through revolving fittings of a big diameter. Accordingly, in a preferred method the fluid material is fed in substantially pressure-free state as at least one strand of the material is generally fluid state into an inlet while distributing it evenly around the circumference by rotation of the die, creating an extrusion pressure at the inlet and/or in the extrusion passage by shear action, and extruding the material to the exit of the die while maintaining it in the form of a tubular stream or a circular array of streams.

Depending e.g. on the flow-properties of

the extruded material, different measures can be preferable to create the extrusion pressure, e.g.:

a) a rolling or scraping action against the inlet c.f. Figures 1 and 6, using rollers, wheels or scrapers that are in engagement with the die and the die rotates relative to them;

b) forming the die of at least two parts which are rotated relative to each other and extruding the material between them. This also produces an overall rotation of the material in one direction. Corrugations may be provided on the surface of at least one of the rotating parts in engagement with the material at an oblique angle to the direction of the tangent, so as to help the pumping towards the exit c.f. Figure 2.

c) similar to (b) but with the use of the Weissenberger effect which means that a viscoelastic material under rotational shear between discs drags towards the axis of the discs due to the elastic forces created by the shear. In this case, it is not necessary to make any surface corrugated, but it is essential that the passageway leads generally inwardly in the zone under shear and that the material used is viscoelastic—c.f. Figure 4,

d) by a fixed insert (e.g. annular) in a circular inlet orifice relative to which one or both surfaces of the inlet orifice rotate, c.f. Figure 3. The insert and/or inlet surfaces can be corrugated as in (b) above or there can be made use of the Weissenberger effect described in (c) above.

When extruding tubular items and using relative rotations as described under (b) or (c) above, it is generally preferable to form the whole die or two parts moving relative to each other from inlet to exit, including any passage in between. In this embodiment the construction of the die is particularly simple.

It is of course necessary to adjust to each other, on one hand the velocity by which the material is fed to the die (normally from a conventional extruder) and on the other hand the velocity of the rotation or rotations which cause the pumping of material through the die. Within limits however, there is a selfcontrolling effect in the means described above under (a) to (d). Thus, to take (b) as an example, the more the inlet orifice is filled with material, the greater will be the portion of the corrugated surface which is covered with material and which therefore participates in the pumping action.

As already mentioned, the grain formed in extruded material in the invention can in many cases with advantage be a grain formed as a result of random blending of materials that are to be extruded. In order to carry out such blending in expedient manner, an embodiment of the above described rotating extrusion with substantially pressure-free feed is characterised in that different materials are fed at different locations to one and the same inlet orifice and are blended during the passage of the exit. One of the different materials can be a mass of solid staple fibres from a substance which does not melt or decompose at the temperatures of the extrusion. The material fed simultaneously with the solid fibres can be molten or dissolved polymer, or a pre-polymer. Due to the distribution by the rotation of the die around its axis, and due to blending that occurs immediately prior to the extrusion, blends with surprisingly high contents of solid fibres can be extruded in satisfactory eveness.

The advantages of side by side extrusion of separate streams have also been mentioned above. In conventional circular co-extrusion, there are constructional complications in obtaining an even circumferential distribution of several components. In this connection, the pressure free feed allows a significant simplification and accordingly a preferred embodiment is characterised in that different extrudable materials are fed into different circular inlet orifices or different circular arrays of inlet orifices, whereafter the materials are brought into interspersed relationship with one another, and are extruded in such relationship. (Reference to Figures 5, 6 and 7).

Various ways of collecting the extruded material and conveying it away can be used. In one, that is particularly precise, collecting is conducted on an endless moving collector from which the material may be finally removed. A very practical way of establishing such cylindrical continuous conveying is by one or several continuously moving belts, which in the zone of collecting are helically wound on a support with the edges immediately adjacent so as to form an essentially cylindrical body in said zone, said helically wound belts being subsequently unwound from said support, while cutting-up the collected material at the location where two adjacent edges are separated from each other. Alternatively, the collector can comprise a rotating generally toroid shaped mandrel. This can be a particularly solid construction able to take up high torsional forces. However, simplest and in many cases fully satisfactory is to use as the collector a continuously forwarded flexible sheet supported by a fixed mandrel.

The material as collected on the conveying means can be very fragile due to the fibrous generally unidirectional substructure, and may even be a transverse array of unconnected filaments. Therefore,

in order to bring the material into self-supporting state, it is often necessary to combine the material with one or more further materials. Such combination can comprise lamination with a reinforcing substance while the material is conveyed by the collecting means. As an example, the reinforcing substance may be fed between the collector and the extruded material. As another example hereof, a sheet used as collector is maintained as a layer in the final sheetlike structure. This is particularly simple and practical, when the sheet is a flexible sheet supported by a fixed mandrel as mentioned above. (Reference to Figure 4).

Alternatively, or additionally, the method of the invention can be carried out from several rotating dies working in line with use of one and the same collecting means, and with the rotations so adapted that the different dies produce a different direction of grain to obtain a cross-laminate. (Reference to Figures 1 and 10). Thus the material extruded from one die serves as the collector for the next.

As mentioned before, the invention enables processing of fluid materials which are otherwise difficult to extrude. This yields a simple way of extruding very valuable sheets having a substructure and formed from dissolved or swollen polymer substances, from blends of such substances with solid fibres, and from blends of solid fibres and prepolymers. In such cases, a rather prolonged solidification process can be involved, and it is in this connection a great advantage that the material is collected and conveyed. When the extruded material is a dissolved or swollen polymer or a blend of dissolved polymer and solid fibres, solidification of the material may involve coagulation and/or drying. When the extruded material is a blend of solid staple fibres and a pre-polymer, solidification of the material may be by after-polymerisation on the collector.

The invention will now be described in more detail with reference to the drawings of which:

Fig. 1 is a schematical perspective view illustrating a preferred embodiment of the method and apparatus according to the invention, showing a pressure-free feed to a rotating die, external rollers as means to set up the extrusion pressure, the use of two counter-rotating independently extruding dies around the same mandrel to produce criss-crossing directions of grain, and a set of conveyor belts that serve as the collector and from which the extruded product is subsequently stripped and which are supported by a mandrel;

Fig. 2 is a schematical perspective view with partial sections illustrating another preferred embodiment of the method and apparatus according to the invention, showing as means to set-up the extrusion pressure two disc-formed die-parts moving with different velocities and supplied with internal guide vanes, further showing a toroidal mandrel as collector, and illustrating a consolidation by chemical treatment while the extruded product is conveyed on the mandrel,

Fig. 3 is a perspective view with partial sections of part of an annular rotating extrusion die for use in the invention, in which the extrusion pressure is set-up by means of an inserted fixed plate, the drawing further serving to show a suitable arrangement of drive and bearings,

Fig. 4 is a schematical perspective view with partial section of still another preferred embodiment of the method and apparatus according to the invention, showing a separate feed of solid staple fibres to the rotating die to be blended with the polymer by the relative rotations of two parts of the die, and further showing the use of a fixed mandrel as a support for a collector which is a sheet which is folded over the mandrel and is laminated with the material collected from the rotating die and forms a layer in the final product,

Figs. 5, 6 and 7 are three different sections which show the main features—a preferred embodiment of the method and apparatus in which two sets of streams of different composition are merged with each other generally side by side in the rotating die and are subsequently attenuated to a fine structure in the space between the die exit and the mandrel, the drawings further showing the use of scrapers in the two inlet grooves of the rotating die as a way of creating an extrusion pressure,

Fig. 8 is a section through the exit part of the rotating die and the mandrel which illustrates the main features of a modification of the embodiment shown in Figs. 5, 6 and 7, by which the two sets of streams are brought in interspersed relationship within the rotating die but are extruded and attenuated separately and are merged into a sheet on the collector,

Fig. 9 is a detail shown in perspective of Fig. 8 with special orifice shapes designed to produce continuous filaments of one component wholly embedded in another component,

Fig. 10 is a schematical perspective view of a further, preferred embodiment of the method and apparatus according to the invention, illustrating the use as collector of a conveyor belt that is wound helically around a mandrel;

The apparatus of Fig. 1 comprises a fixed mandrel (1) that serves as the support for

three endless conveyor belts (2) that mainly cover the surface of the mandrel and that serve as a collector. After cooling of the film extruded onto the belts it is cut up and rolled on bobbins (4) and (5).

The apparatus shown also comprises a composite annular die (3) formed of two counter-rotating annular dies (6) and (7). Each die has extrusion passages each leading inwardly from an inlet to an outlet. Each inlet is fed by fluid material pressure free by supply extruders of which only two, (8) and (9), are shown. Streams emerging from two other extruders (not shown) are indicated by (10) and (11). Rollers (12) press the fluid polymer or other material into circular inlet grooves (13) which can conveniently be heated by hot air, e.g. from within the annulus. The rollers may be substituted by scrapers heated e.g. by a cycloterm.

The extrusion-die (3) may be heated from only one location as the rotation of the die will distribute the heat. Induction heating may be used, and the temperature may be controlled by pyrometers.

Each inlet groove (13) is connected with one or several exit orifices (not shown). The extrusion-die (3) can be fed from fewer or more extruders and the die could consist of one, two or more rotating or counter-rotating single dies, optionally with fixed extrusion dies in between. Thus in the invention although it is essential for one annular die to rotate fast as described, there may also be one or more non rotating annular dies.

A pronounced advantage of combining several single dies around one mandrel is that the layers of a composite sheet may be extruded successively over each other but under relatively independent of one another so that each layer may be treated individually e.g. as to heat. The exit from the extrusion passage through the die can be in the form of a circular exit slot or slots or of one or more orifices or a circular row of orifices. The exit or exits can be situated on the inside surface of the annular extruder die, which is convenient for fast rotation of the die or, at the end surface of the die, which may be convenient when the die rotates more slowly but preferably is near the interface between the inner and end surfaces since the conditions for simultaneously controlling and cooling the polymer stream at this point are optimal.

While it is expected that the rolling or scraping action described in connection with Fig. 1 is especially efficient in connection with material of particularly low fluidity, e.g. very high molecular weight polymers, the extrusion die of Fig. 2 is preferred in many other cases due to its simplicity. The die is fed with a pressure free stream or strand from an extruder outlet (14) and consists of two unconnected parts (15) and (16) which define a conduit consisting of the inlet orifice (17) leading directly to an exit orifice (18). (There may however conveniently be a longer passageway between the inlet and exit comprising one or several widened chambers for further improvement of the distribution).

The two parts (15) and (16) are held in position and in the proper distance from each other through external bearings and are driven at different velocities through gear wheels (for details regarding the arrangement of bearings and gear wheels: see Fig. 3). The different velocities are indicated by the two arrows of different length. In order to achieve an efficient pumping action, the walls of the inlet orifice can be supplied with suitable vanes (19) which here are only shown on one of the parts. However a sufficient pumping action can often be obtained without such vanes or corrugations due to the known tendency in viscoelastic material to drag inwardly when applied between discs which counterrotate (the Weissenberger effect).

At the same time as the two parts (15) and (16) move relative to each other, it is essential that the material fed into the die is extruded from the exit (18) with a strong rotation in order to become properly distributed. The arrows indicate that in the drawing both parts rotate in the same direction but at different velocities. However one part may be stationary or the two parts may even be rotated in opposite directions, provided the difference in their numerical velocities is sufficiently large that the material has, overall, a strong rotation in one direction.

Also in this embodiment the heating of the die can be by induction, but due to the simplicity and compactness of the construction it is even possible to use open flames.

The exit orifice can be a plain circular slot extruding a tubular film—as indicated at (18)—or alternatively it can be supplied with corrugations—as indicated at (20) adapted to extrude a circular array of filaments. When the distance from the die exit to the collecting mandrel (21) is short, the risk of breaking such fibres is greatly reduced, and a layer of fine fibres can be produced even from a rather unevenly corrugated exit slot.

The collecting and forwarding mandrel (21) is of toroidal shape and is supported and continuously driven in the direction of the arrow (22) by means of a series of driven wheels of which one (23) is shown.

In order to facilitate the support and drive, the inner part of the toroidal mandrel is supplied with a deep narrow groove (24)

with which the wheels fit. The wheels (23) may conveniently be gear-wheels fitting with a gearing in the groove of the mandrel.

The invention is very suitable for materials which require a relatively complicated or prolongated treatment, e.g. coagulation of dissolved polymer, or other chemical treatment. Such treatment is indicated by the circular airless spray (25) from which e.g. a solution for coagulation can be sprayed onto the material. Similarly there can be special heating and/or cooling means and/or irradiation means in conjunction with the mandrel.

Before being stripped off from the mandrel, the material is cut, conveniently at the place of the groove (24), as shown by the rotating knife (26). There can also be scrapers or the like (not shown) to remove extruded material.

Since this apparatus does not require complex pressure seals the die can easily be manufactured with a relatively large diameter, e.g. 1—2 m. The toroidal mandrel can conveniently have a main diameter 5—20 times that of the inner diameter of the die, and should in practice be assembled from several preferably hollow sections.

In Fig. 2 the opposite sides of the exit slot rotate to each other. The shear at the exit can introduce tensions which under certain rheological conditions can introduce instabilities during the draw down and attenuation that occurs before and during collection of the extruded material.

The embodiment shown in Fig. 3, takes care of this difficulty since it allows the two parts (15) and (16) to rotate at the same velocity (and in the same direction).

If the die is designed for extrusion of an array of filaments they can be provided by extrusion through orifices in the exit.

The extrusion pressure is achieved by means of a stationary ring-formed insert (27) fixed through several supports of which one (28) is shown. This establishes a driving shear between the insert (27) and each of the parts (15) and (18).

The insert is shown supplied with vanes (29) but there can additionally or alternatively be vanes or corrugations on the inlet orifices surfaces of (15) and (16) or all vanes and corrugations can be omitted. Preferably one or several strands of material are fed on each side of the insert (27).

This drawing further shows the bearings (30) and (31) for each of the dieparts (15) and (16).

In Fig. 4 there is fed to the annular die simultaneously a pressure free feed of polymer from the extruder outlet (14) and a web (32) of staple fibres which have a melting point higher than the processing temperature of the die. Suitable fibres are inorganic fibres such as glass, asbestos or rockwool. The feed is shown taking place by means of a conveyor belt but could also be by any other means. The die is shown without any internal vanes or corrugations, i.e. the extrusion pressure is set-up entirely by the Weisenberger effect. In fact, a slight corrugation is generally preferable, while strong shear forces may cause excessive breaking of the fibres. It should be noted that a direct feed of fibres into the die is highly preferable compared with a prior admixture of the fibres to the polymer and common feeding through (14) since it results in a more even feed and much less fibre breakage, and permits much higher fibre contents to be used.

The mixing of fibres and fluid polymer takes place partly at the feed and partly by the shear exerted during the passage towards the circular exit slot (18). The collector is a flat sheet (35) that is folded to a tubular shape around the mandrel (34) which supports the sheet. The sheet (35) may be produced e.g. from a flat die in line with the rotating extrusion or may be produced beforehand. The sheet collector moves while the supporting mandrel is stationary.

For the sake of clarity a space is shown between the mandrel (34) and the folded sheet (35), but of course the sheet is in a close sliding fit over the mandrel. The sheet (35) is pulled through the extrusion die over the mandrel as indicated by the arrow (36). When the polymer film in molten state leaves the rotating exit slot (18) it is strongly melt-stretched (attenuated) and the fibres are aligned in the direction of attenuation, and it is collected and held by the folded sheet (35) because of the elastic retention in the attenuated polymer. Thus it is wound around the folded sheet and forwarded along with it, resulting in a strongly helical grain as indicated by the broken line (37).

The forward movement of the sheet (35) is established by conveyor belts (38). The mandrel is preferably supplied with cooling means (not shown). The contraction of the extruded material can conveniently be matched by a gradual reduction of the diameter of the mandrel.

The conveyor sheet (35) may be formed of the same polymer as the material that is being extruded onto it, but if necessary an adhesive can be applied to ensure that the collector sheet will be laminated with the extruded material to form a layer in the final product.

The product so manufactured is a tube or pipe having transverse reinforcement, and its strength characteristics can be improved still further by the use of two extrusion dies (see Fig. 1) and/or by inclusion of longitudinally arranged fibres in the collector sheet.

The feature of laminating the collector with the extruded material is neither restricted to the application in conjunction with a feed of higher melting fibres to the rotating die, nor to the production of reinforced pipes or tubes, but has many other applications in connection with consolidation or reinforcement of rotatingly extruded material.

The die shown in different sections in Figures 5, 6 and 7 consists of three parts, viz, an inlet and manifold part (39) and two separate exit half-parts (40) and (41). The three parts are rotated around the axis (42) by drives (43), (44) and (45) respectively, all in the same direction and all three with relatively high velocity. The two exit half-parts (40) and (41) move at the same velocity, and the relative velocity between these parts and the first part (39) is low compared to their absolute velocities. The die is fed from two extruder outlets (46) and (47) into circumferential grooves (48) and (49). Pressure is applied to the two different polymer materials (50) and (51) by rows of scrapers (52), and the materials are fed through two rows of passageways (53) and (54). Streams of the materials from these passageways are brought into side by side relationship and extruded through a circular row of alternating orifices (55) and (56) into a short annular collecting chamber (57) that is formed between the two parts (40) and (41), and which leads into a circular exit slot (58). From the exit slot (58) the two sets of juxtaposed streams are extruded in the form of a composite tubular sheet (59) onto the cylindrical collector, here shown as a toroid (60).

In the collecting chamber (57) and the exit slot (58), the interspersed streams still have a relatively coarse configuration, limited in structure fineness by the pitch of the row of orifices (55) and (56), but when the composite fluid sheet is attenuated between the relatively fast rotating circular exit slot (58) and the mandrel (60), each part-stream is strongly attenuated and is converted to a thin ribbon or lamella shape. The ribbons can be attenuated to a few microns thickness, or less, by providing sufficiently high velocities.

The resultant sheet has a "lamellar structure", i.e. a sheet substructure constituted of thin elements which form an angle to the surface of the sheet. Other methods of producing a lamellar structure are disclosed e.g. in US Patent Nos. 3,505,162, 3,565,744 and 3,677,873, where e.g. the application of this substructure is explained. However the method described above allows much stronger and regular attenuation and hence a formation of a finer regular substructure.

As appears from Figure 7 the slots (55) are longer than the slots (56) and extend further on both sides of the centre of the 39, shown by line 55a, then slots 56 collecting chamber (57) relative to the slots, material extruded through the longer slots will be smeared out to form continuous layers on both surfaces. This feature as such is known from the above-mentioned US Patent No. 3,565,744 where it is further explained. If such effects are not desired, for instance when, it is desirable to produce a "lamellar" substructure with all lamellae traversing from one sheet surface to the other there is no need to move the exit 58 of the die in relation to the passageways (53) and (54). The orifices (55) and (56) can then preferably be of equal length and symmetrically positioned with respect to each other and the line 55a. It is obvious that this embodiment of the invention can be carried out also with three or more components coextruded and interspersed with one another.

In Figure 8 the side by side extrusion system explained above is modified by omitting the independent half-parts (40) and (41) and by extending the extrusion passageways (53a) and (54a) all way through to the exit of the die, from where the two components are extruded directly into the space between the rotating die and the mandrel (61) through a circular array of protruding exit orifices (62) and (63). The fibres of different materials (64) and (65) respectively are attenuated generally tangentially with respect to the mandrel and are collected and forwarded on the latter in interspersed relationship. The protruding design of the orifices (62) and (63) facilitates the release of the material from the die.

If the exit orifices (62) and (63) are slots having a significant length in the axial direction of the die, they will extrude ribbon-filaments which will be collected on the mandrel in overlapping manner, generally as a "lamellar structure". A much more irregular, but more truly fibrous interspersed sheet substructure, is usually achieved if the orifices are relatively short in the axial direction.

In Figure 9 the exit orifices (62) for one component are very elongated slots while each of the orifices (63) for the other component is a row of small sub-orifices (66). The ribbons extruded through (62) will be collected in overlapping arrangement like shingles, while each of the filaments extruded through a part-orifice (64) will be embedded between a pair of the ribbons. The merged ribbons will thus form a matrix for the filaments of the other material. The diameter of the fibres so produced can e.g. be 1 to 20 denier many times smaller than the thickness of the sheet, and they can be

arranged so densely that they occupy e.g. 50 to 90% of the entire sheet.

Although several methods are known for coextrusion of continuous filaments in a sheet matrix, none of these enable the obtaining of similar fibre fineness simultaneously with a similar fibre density. The sheet so produced is very suitable e.g. as a layer in high-strength film. For this purpose, the filaments should preferably consist of highly crystalline polymer (e.g. polypropylene) and the matrix of a much softer and less crystalline polymer (e.g. low density polyethylene).

Comparing the embodiment shown in Figures 5, 6 and 7 with the modification hereof shown in Figure 8 or 9, the merging of streams into sheet-form prior to the discharge through the exit slot generally allows higher throughputs and a higher degree of attenuation between die and mandrel without breakage. However optimal results are only obtained if the melt-viscosities of the different materials match relatively well. When, on the other hand, the individual streams are attenuated pressure-free and the joining takes place on the mandrel (c.f. Figure 8) there is no need to match the melt viscosities. A kind of compromise between the two systems can also be used, viz, to extrude the streams separately from the exit, on the inside circumference of the rotating die, and adapt the forward velocity of the mandrel to the total throughput of the two components so that the space between die and mandrel is filled-up with polymer without creation of an excess of pressure in this space. In other words, the space between die and mandrel serves as a collecting chamber in which the interspersed streams are smeared out by the rotation. In this case, protrusion of the exit orifices should preferably be avoided.

Another way of utilising the side by side streams generated by the passageways (53) and (54) of Figure 5 is to form the two (or more) different materials into an array of conjugent filaments or ribbons which are extruded separately and collected and bonded together on the mandrel. Each conjugent filament may either have the materials in ordinary side-by-side relationship or in a sheaf/core relationship or any other convenient conjugent relationship.

Instead of collecting the conjugent filaments into a continuous sheet on the mandrel, the throughputs, die rotation and mandrel velocity can be selected so that they are collected as an open set of spiral-laid filaments, which can subsequently be combined with similar conjugent filaments, laid-up by a die rotating in the opposite direction, c.f. Figure 1. The two sets of filaments can conveniently be fused together, while still on the mandrel, at a temperature at which one component is molten and the other one solid.

In Figure 10 an endless continuously moved conveyor belt (67) is wound helically around a fixed mandrel (68) in such a way that its left edge (69) fits with its right edge (70). Thus it serves as a collector in the hollow centre of a die (71) and acts there as if it was an endless cylinder that is continuously being screwed forward. At the point where the belt is unwound, a knife (72) cuts the collected extruded material in order to release the belt from the mandrel. If the die rotates very fast compared to the movement of the belt, the direction of grain in the extruded material will be almost 45° to the length direction of the belt, as shown by arrows (73). The same belt may be passed over and around another mandrel (74) having its axis perpendicular to the axis of mandrel 68, that extends through another rotating die (75), and this results in the formation of another layer of material having its direction of grain (76) almost perpendicular to the direction (73).

The driving means are not shown. The mandrels (68) and (74) can conveniently be supplied with special bearings to facilitate the movement of the conveyor belt (67). The procedure can be carried out without any use of a mandrel to support the belt (67) provided the latter has a convenient stiffness and is supported by suitable bearings.

The above description of the drawings has dealt with different aspects of the invention including different ways of setting-up an extrusion pressure in a pressure-free fed rotating die, the feed of solid fibres to the rotating die, the interspersing of streams of different materials prior to the take-up on the collector, different collectors and different ways of consolidating the sheet. The different aspects described can of course be combined in many ways other than those expressly mentioned.

WHAT I CLAIM IS:—

1. A method of making an extruded product comprising extruding fluid material through an annular bie to an extrusion exit while rotating the die around the axis of the annulus and collecting the extruded material on a collector while moving the collector substantially along the axis of the annulus, wherein the collector, at least in the area where it collects the extruded material, is substantially cylindrical and is substantially coaxial with the annulus and comprises an internal support for the extruded material or is supported by an internal support, and in which method the speed or rotation of the die and of movement of the collector are such that the

extruded material is stretched and is given a grain direction on the collector that is at a substantial angle to the axis of the annulus, and the extruded material after solidification is released from the support.

2. A method according to claim 1 in which the stretching is carried out in a free space between the exit and the collector.

3. A method according to claim 1 in which the stretching is carried out in a generally annular shear-chamber defined by the inner face of the rotating die and the collector, the rates of extrusion and collecting being adjusted with respect to each other so as to maintain the chamber filled with material in a substantially pressure-free state.

4. A method according to claim 1 in which the material is extruded from the exit of the rotating die in the form of separate filaments and the rates of extrusion, rotation and movement of the collector are adjusted with respect to one another that the filaments form a continuous sheet structure when they are collected.

5. A method according to claim 1 in which streams of different materials are extruded in side by side relationship and are merged with one another.

6. A method according to claim 5 in which at least part of the merging is carried out before the passage through the exit of the rotating die.

7. A method according to claim 5 in which at least part of the merging is carried out in a shear-chamber between the exit and the collector.

8. A method according to claim 5 in which at least part of the merging is carried out on the collector.

9. A method according to claim 5 in which the streams of different materials are merged in a regular pattern in which one material is embedded, at least in part, in another material.

10. A method according to claim 9 in which, the exit through which a first material is extruded is in the form of a multitude of relatively long slots extending in the axial direction of annulus and arranged in a circular array around the annulus and the exit through which the second material is extruded is in the form of groups of smaller orifices between the longer slots, and the materials are merged substantially immediately after extrusion.

11. A method according to claim 1 in which the extruded material is a non-homogeneous blend of fluid polymers and a continuous sheet structure is discharged from the exit.

12. A method according to claim 1 in which the discharged material is a blend of fluid polymer material and solid staple fibres, and a continuous sheet structure is discharged from the exit.

13. A method according to claim 1 in which the extruded material is a molten polymer of high molecular weight and capable of segregating into different distinct fibrous polymer fractions when stretched in molten state and solidified, and a continuous sheet structure is extruded from the exit.

14. A method according to claim 1 in which the discharged material is a polymer which contains a solvent or swelling agent, and a continuous sheet structure is extruded from the exit, and in which the solvent or swelling agent is caused to segregate in the polymer during the solidification.

15. A method according to claim 1 in which the discharged material is a polymer which contains dispersed droplets or bubbles of liquid matter, and a continuous sheet structure is extruded from the exit.

16. A method according to claim 1 in which the fluid material is extruded by feeding it in substantially pressure free state into an inlet, while distributing it evenly around the circumference of the die by the rotation of the die, creating an extrusion pressure at the inlet and/or during the passage towards the exit extruding the material to the exit of the die while maintaining it in the form of a tubular stream or a circular array of streams.

17. A method according to claim 16 in which the extrusion pressure is created by a rolling action against the or each inlet orifice.

18. A method according to claim 16 in which the extrusion pressure is created by a scraping action againt the or each inlet orifice.

19. A method according to claim 16 in which the die is formed of at least two die parts and the material is extruded between them and in which extrusion pressure is created by rotating the parts relative to each other.

20. A method according to claim 19 in which there is a corrugated surface on at least one of the facing surfaces of the die parts designed to create a pumping action to facilitate extrusion.

21. A method according to claim 19 in which the inlet, the exit, and any passage between the inlet and exit are defined by the die parts.

22. A method according to claim 16 in which the extrusion pressure is created between the walls of the inlet and a fixed insert in the inlet.

23. A method according to claim 16 in which different materials are fed separately to one and the same inlet and are blended during the passage to the exit.

24. A method according to claim 23 in

which at least one of the different materials is a mass of solid staple fibres made from a substance which does not melt or decompose at the temperatures of the extrusion.

25. A method according to claim 16 in which different extrudable materials are fed into different circular inlet orifices or different circular arrays of inlet orifices, whereafter the materials are brought into interspersed relationship with one another, and are extruded in such relationship.

26. A method according to claim 1 in which the extruded material is released from the collector after solidification.

27. A method according to claim 26 in which the collector comprises one or more endless belts, which in the area of collection are helically wound on a cylindrical support with their edges immediately adjacent so as to form an essentially cylindrical body in the area and the one or more belts are subsequently unwound from the support while cutting-up the collected material at the location where two adjacent edges are separated from each other.

28. A method according to claim 26 in which the collector comprises a rotating generally toroid shaped mandrel.

29. A method according to claim 1 in which the collector comprises a flexible sheet that is moved continuously forward and that is supported by a fixed mandrel.

30. A method according to claim 1 in which the extruded material is laminated with one or more further materials before being released from the support.

31. A method according to claim 30 in which the collector comprises a sheet that is maintained as a layer in the released product.

32. A method according to claim 30 in which there are two separate annular dies and material is extruded from one die and collected on a collector with its grain in one direction and material is extruded from the other die and the collected material from the first die is used as the collector on which the material from the said other die is collected with its grain in a different direction.

33. A method according to claim 1 in which the fluid material is a dissolved or swollen polymer, or a blend of dissolved polymer and solid fibres, and is solidified by coagulation and/or drying on the collector.

34. A method according to claim 1 in which the fluid material comprises a blend of solid staple fibres and a pre-polymer, and is solidified by after-polymerisation on the collector.

35. A method according to claim 1 substantially as herein described with reference to any of the drawings.

36. Apparatus suitable for use in a method according to claim 1 comprising a rotatable annular die having an extrusion passage leading to an extrusion exit, means for feeding fluid material to the extrusion passage and extruding it from the exit, and means for moving a collector on which material extruded from the exit may be collected substantially along the axis of the annulus, wherein the collector at least in the area where it collects the extruded material is substantially cylindrical and is substantially coaxial with the annulus and comprises an internal support for the extruded material or is supported by an internal support, and means for rotating the die and moving the collector such that the extruded material is stretched and is given a grain direction on the collector that is at a substantial angle to the axis of the annulus, and means for releasing the extruded material from the support after solidification.

37. An apparatus according to claim 36 which has means for feeding the fluid material in a generally pressure-free state to an inlet of the rotatable die, and means for creating an extrusion pressure at the inlet and/or during the passage towards the exit.

38. An apparatus according to claim 37 in which the inlet is located at a convex circular surface of the die.

39. An apparatus according to claim 37 wherein the inlet is a circular orifice, and wherein means are provided for separately feeding solid fibres into the same inlet orifice.

40. An apparatus according to claim 37 comprising a die having at least a first and a second circular inlet orifice or circular row of inlet orifices, and having a first and a second set of passageways extending from the first and second circular inlet orifice or row of orifices respectively, to a collecting chamber or directly to the exit of the die, and wherein the first set of passageways converges with the second set of passageways in a side by side relationship.

41. An apparatus according to claim 36 in which the collector is an endless collector and including means for moving this continuously through the central space.

42. An apparatus according to claim 41 in which the collector comprises a rotatable toroid shaped mandrel.

43. An apparatus according to claim 41 in which the collector comprises one or more endless belts, which in the zone of collecting are helically wound on a support with immediately adjacent edges, so as to form essentially a cylindrical body.

44. An apparatus according to claim 36 comprising a fixed cylindrical mandrel located within the central space and means for continuously passing a collector sheet over the mandrel.

45. An apparatus according to claim 37 wherein the means for creating the extrusion pressure comprises a circumferential array of rollers, wheels or scrapers in engagement with the inlet to the die, the inlet being rotatable in relation to said means.

46. An apparatus according to claim 37 wherein the inlet to the die is a circular slot defined by two die parts rotatable at different velocities.

47. An apparatus according to claim 37 wherein the means for creating the extrusion pressure comprises a fixed insert in a rotatable inlet to the extrusion die.

48. Extruded material made by a method according to any of claims 1 to 35.

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1553102 COMPLETE SPECIFICATION

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Sheet 1

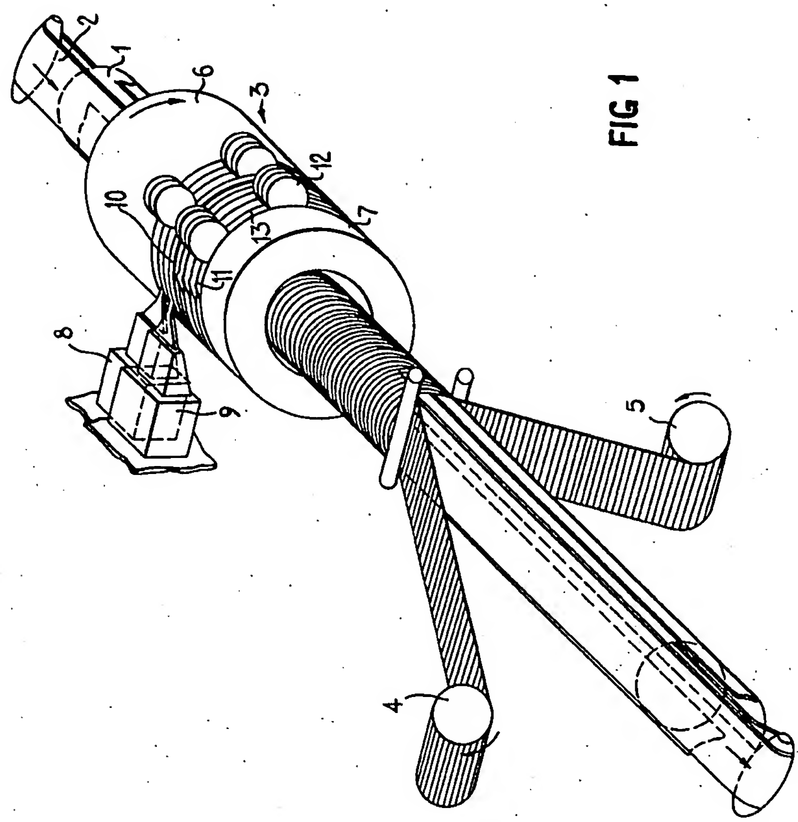

FIG 1

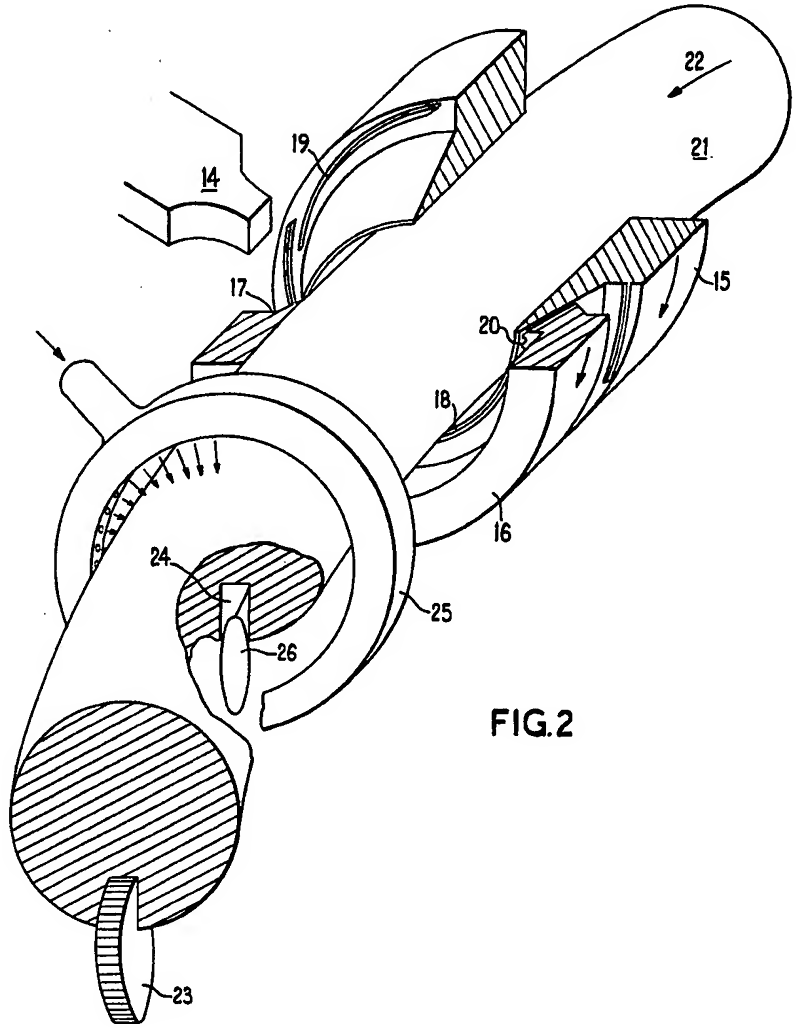

FIG.2

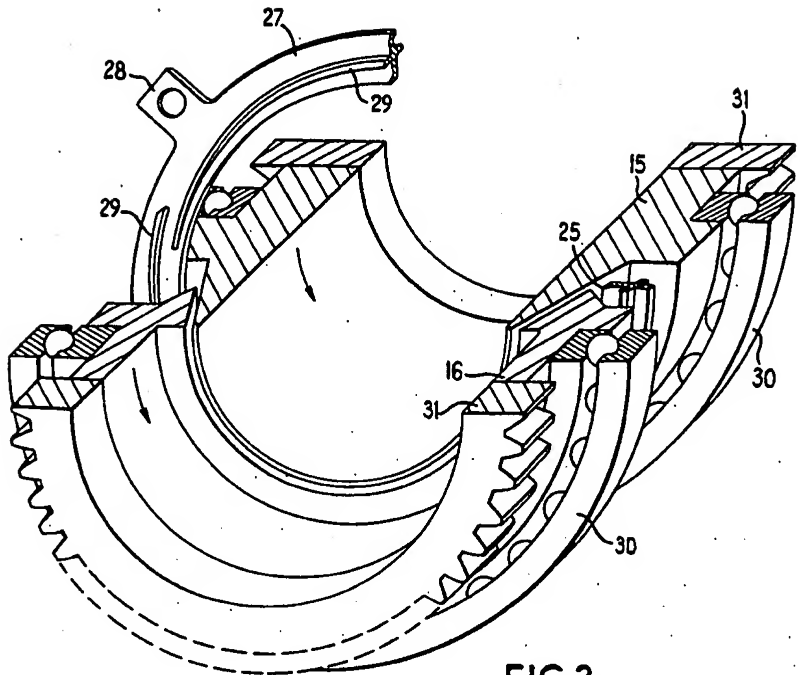

FIG.3

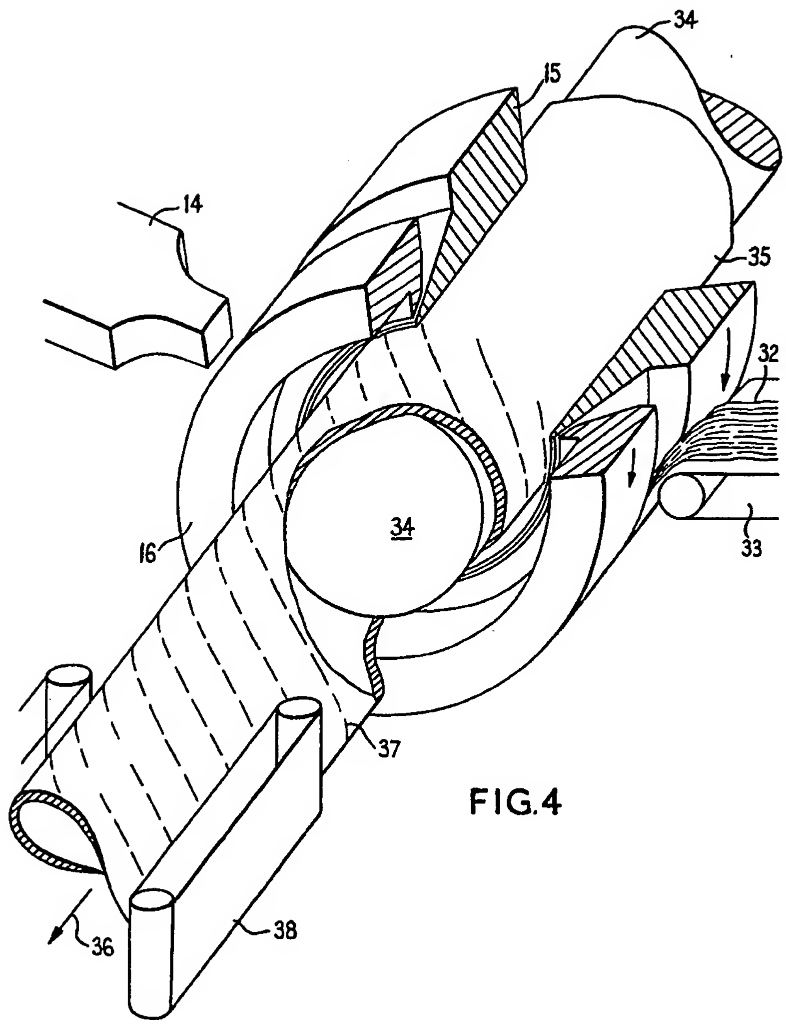

FIG.4

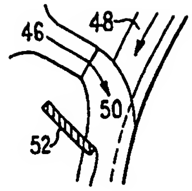

FIG.6

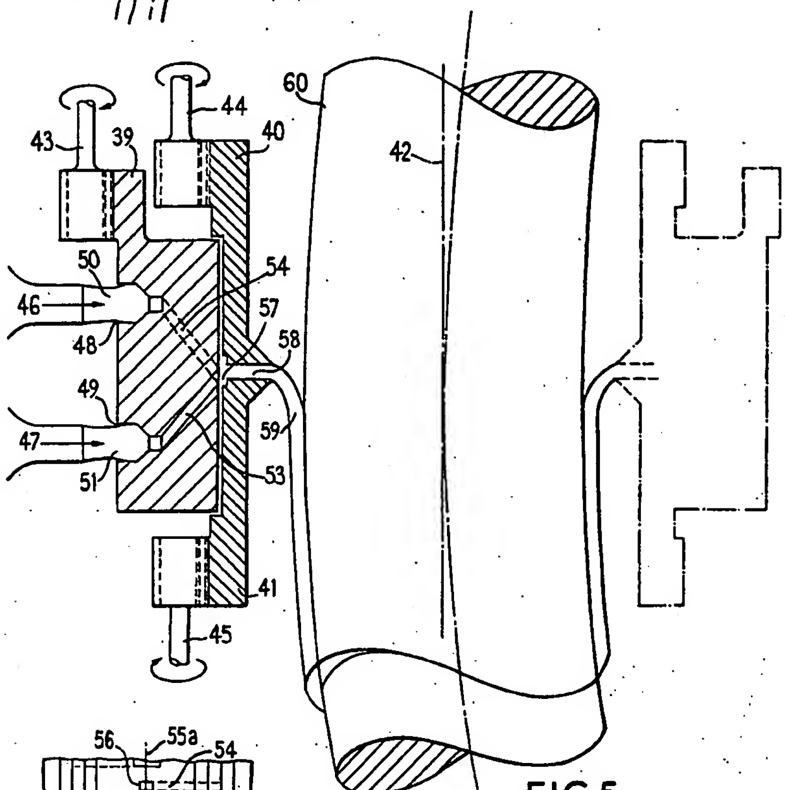

FIG.5

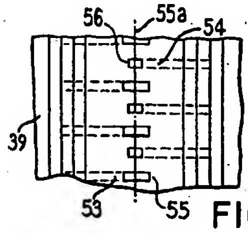

FIG.7

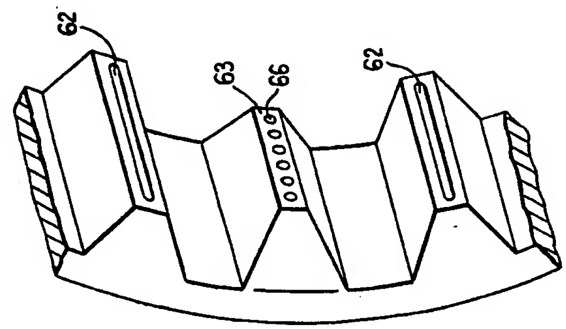

FIG.9

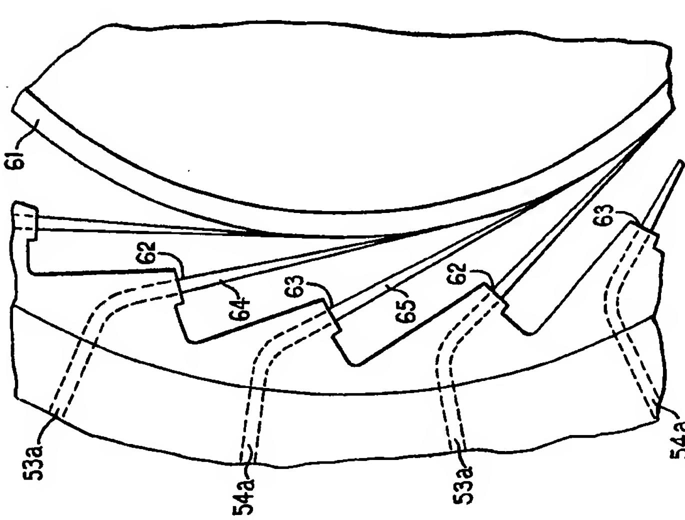

FIG.8

1553102 COMPLETE SPECIFICATION

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Sheet 7

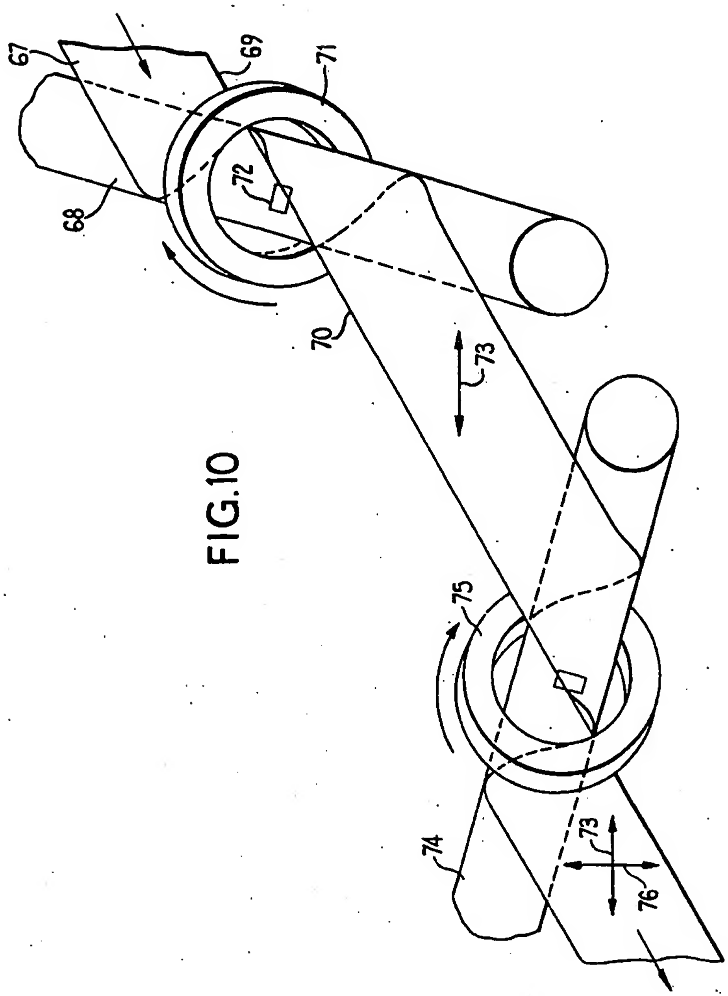

FIG.10